Current Needs in Reactor Physics: For The Nuclear Power Industry

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Presentation Caveats

- This talk represents my personal views on reactor physics needs – not a detailed technical analysis of the area
- My experience is highly biased towards needs of the commercial LWR industry
- Apologies to those with CANDUs, RMBKs, etc.

What are the nuclear power industry current needs in reactor physics

- New plant requirements (or new plants themselves) to justify the need for improved reactor physics methods
- Utility management who understands the importance of reactor physics in plant operations
- Reactor physicists who understand the importance of plant operations to the nuclear power utility
- Resources (i.e., time and $) for reactor physicists to devote to reactor-physics-related tasks

Why new plant requirements?

- 5+ years needed for development of new methods or codes
- 3+ years needed for licensing of new codes
- 5+ years needed for new products to penetrate the market
- 5+ year "moratorium" on new methods prior to plant closure

> 18 years of subsequent plant operation may be required to justify starting the development of significant new reactor physics methods or codes

Why are reactor physics projects needed?

- Routine reactor physics analyses are now performed with personnel using "black box" codes/tools which have been very successful in:
  - Improving the accuracy and human efficiency of reactor physics analysis
  - Removing much of the need for detailed understanding of reactor physics
  - Isolating reactor physicists from much of the fundamental reactor physics
  - Reducing the need for reactor physicists to learn how to "approximate"
- Aging of existing reactor physicists results in a continuous loss of practical reactor physics knowledge
  - How many existing reactor physicists are actually doing reactor physics?
  - How many reactor physicists have participated in the application of new methods for analyzing reactors that have actually been built?
- Significant new projects (followed to completion) enhance the learning experience and expand reactor physics understanding

Why do reactor physicists need to understand the “Big Picture”?

- Reactor physics challenges will not be solved by the introduction or perfection of any single tool:
  - Complete reactor analysis requires:
    - 10,000s of steady-state 3-D core calculations
    - 100s of transient core calculations
    - 1000s of operational support calculations
    - Continuous real-time core monitoring calculations
  - Reactor design/construction is largely determined by economics (i.e., money makes the real decisions)
  - Reactor operations are often limited by uncertainties (e.g. system generation requirements, economic market, mechanical failures, etc.)
  - Accuracy of methods will ultimately be limited by: fabrication tolerances, operational unknowns, stochastic variations, etc.

Why do reactor physicists need to understand other disciplines?

- Reactor physics requires better cooperation with other disciplines because fuel/reactor performance is limited by knowledge of:
  - material changes with irradiation:
    (e.g., pin and channel growth and bowing)
  - chemistry interactions with fuel and components:
    (e.g., crud deposition, oxidation, hydriding, etc.)
  - detailed thermal hydraulic conditions:
    (e.g., fuel spacer effects, local dryout conditions, DNBR margin, etc.)
  - gross thermal hydraulic conditions:
    (e.g., plenum mixing, bypass flows, pressure drops, etc.)
- Broad knowledge of inter-related disciplines will be required to permit reactor physics gains to be fully realized
- Other disciplines are probably not going to be learning reactor physics!

Nuclear Data Needs

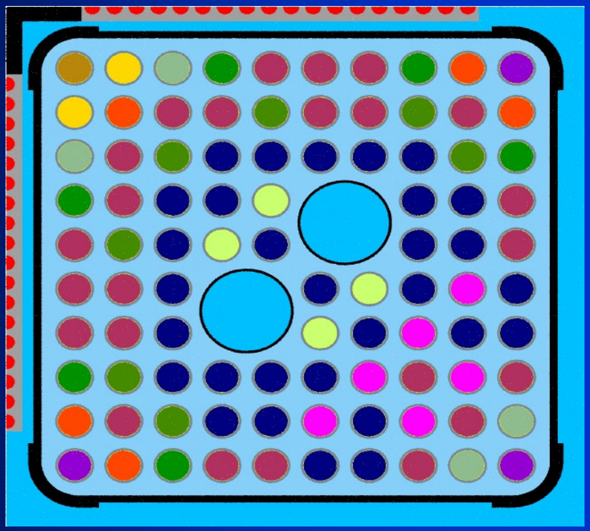
- Physicists who understand existing nuclear data and nuclear models
- Better testing of new data libraries:
  - JEF3, ENDF-B/6, JENDL3, etc.
- Improved accuracy of nuclear data:
  - Better actinide data for ultra high burnup applications
  - Better actinide data for actinide burning through re-cycling
  - Better fission product data (still many errors and missing data)
  - Better data to support alternate fuel cycles
  - More complete covariance data for understanding uncertainties
  - More accurate delayed neutron data
- Better code support and quality control of data processing tools (e.g., NJOY)

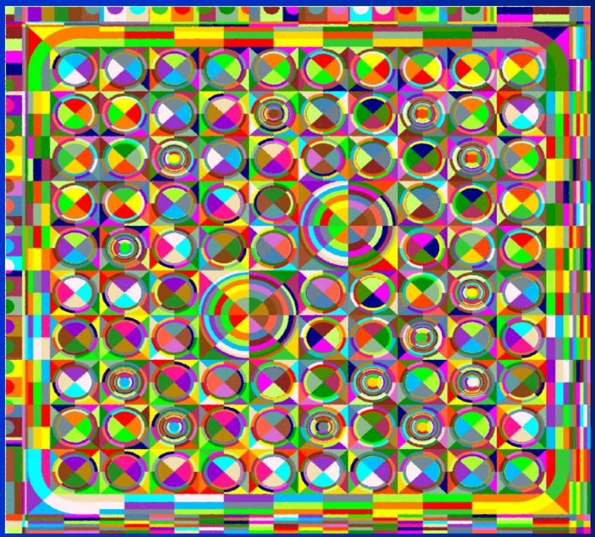
Critical Experiment Needs

- Commitments to keep some critical facilities operating
- Training of more young people in experimental techniques
- Focus on the tough critical experiments:
  - Local distributions of fission and absorption
  - Fuel depletion effects and fission product poisoning
  - Delayed neutrons yields
  - Spent fuel (sub) criticality
- BOL critical experiments are probably not worth their cost given the present status of analytical methods

Lattice Physics Methods

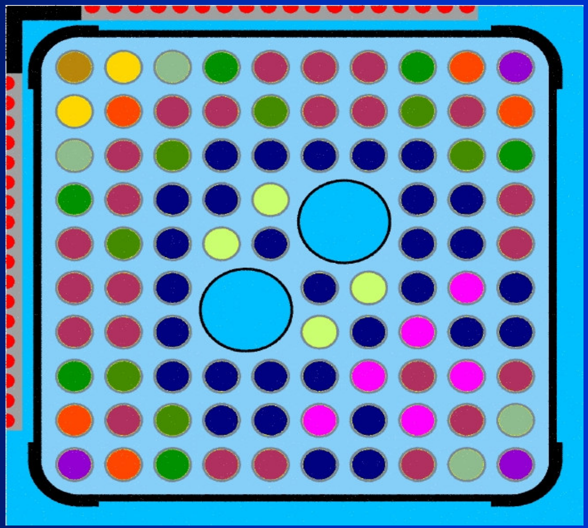
- 2-D multi-group transport is largely a solved problem
  - Exact heterogeneous geometry is the industry standard
  - Multiple radial/azimuthal depletion rings within a pin are required
  - Extensive nuclide tracking is a necessity: >300 isotopes
- Resonance model are the weak link of modern lattice physics codes and need improvement

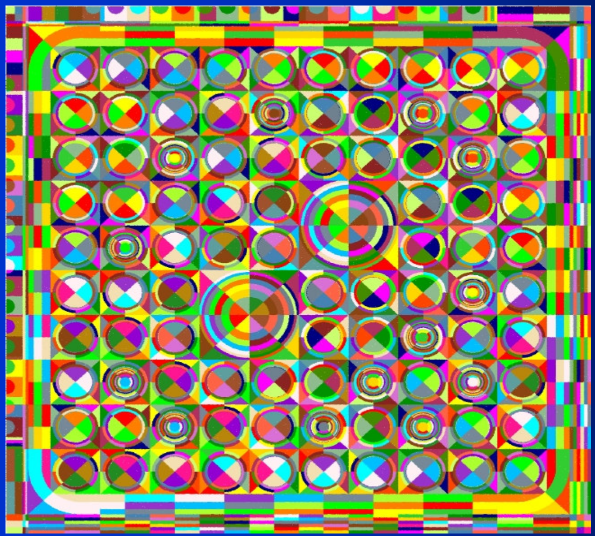




Monte Carlo Lattice Methods?

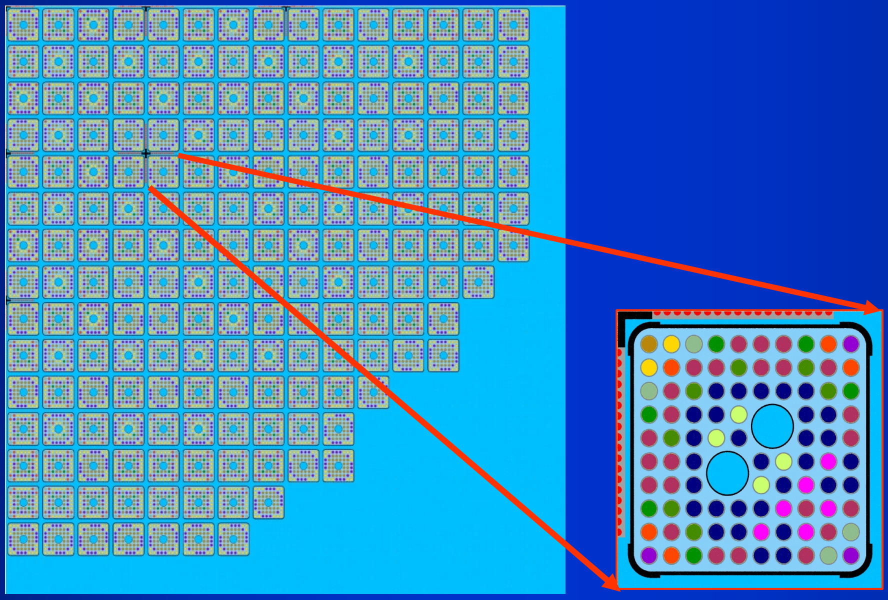
- Requirements:
  - 1000's of 2-D calculations required per fuel bundle
  - Many tally regions for radial and azimuthal pin depletion
  - Lots of isotopes for decay heat and radiological sources
- When will they be practical?
  - Not real soon, but they are coming!





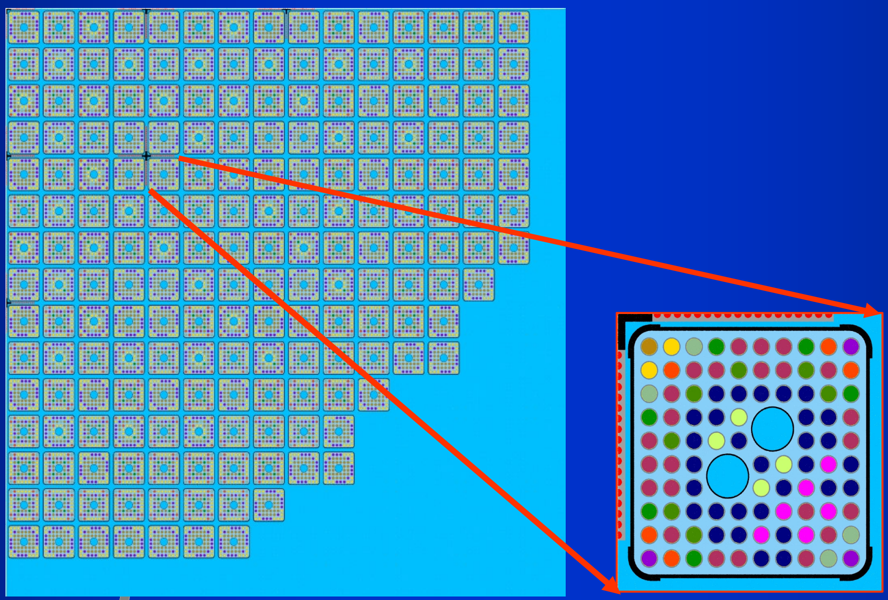
Current 3-D nodal methods

- Requirements: ~1% accuracy on pin-wise powers
  - Numerous variants of advanced nodal methods
  - Intra-nodal space and spectrum dependencies
  - Multi-group, microscopic or macroscopic depletion
  - Accurate pin power reconstruction



Current limitations of nodal methods

- Deficiencies in current LWR nodal methods:
  - Inaccuracy causes big by large spectrum mismatches between fuel
  - Inability to treat accurately intra-assembly flux gradient effects (re-homogenization)
  - Inaccuracy caused by BWR blade history effects on pin powers
  - Inability to accurately predict thermal-hydraulic distributions (coolant densities and fuel temperatures)



3-D Monte Carlo analysis?

- Overcome difficulties with source convergence for typical LWR dominance ratios (> 0.995)
- Drastic increase in number of histories to achieve 1% statistics on local pin powers
- Drastic increase in tally efficiencies for very large problems
- Overcome massive data storage (100,000 pins x 500 axial levels x 300 isotopes = 60 Giga-bytes per depletion point)
- Treat 1000s of calculations per cycle of operation
- Introduction of thermal-hydraulic feedback required for accuracy

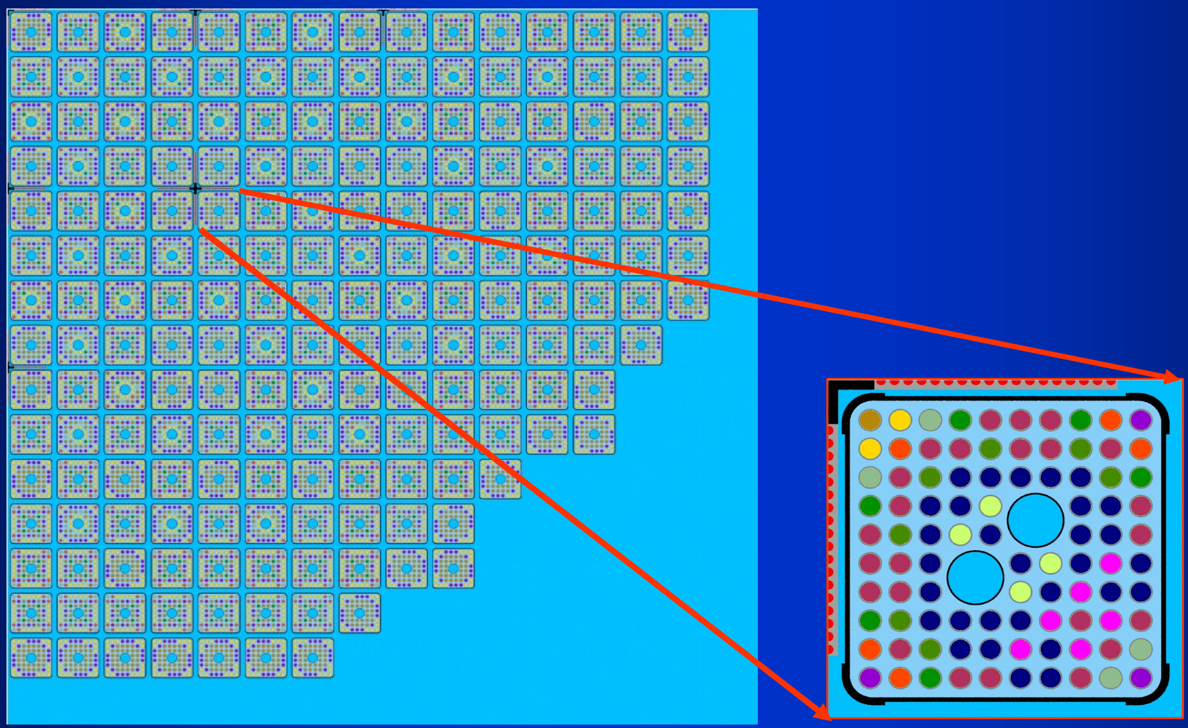
- Full-core Monte Carlo not realistically achievable for production analysis (at least for LWRs) in next 20 years

New 3-D pin-cell based methods?

- Modern computers make possible very large computational problems
- 3-D pin-by-pin computations are possible
- Difficulties:
  - Need for transport-to-diffusion corrections
  - Need for homogenization approximations (at pin-cell)
  - Pin-cell cross section approximations (environmental effects)
  - Large data storage requirements (100,000 pins x 500 axial levels x 300 isotopes = 60 Giga-bytes per depletion point)
  - Isotopic depletions become dominant computational burden

New 2-D heterogeneous/3-D methods

- Accurate and efficient axial transport models required
- Brute force data storage requirements (100,000 pins x 10 radial rings x 100 axial levels x 300 isotopes = 120 Giga-bytes per point)



Core-loading optimization methods

- Modern computing has made single-cycle rigorous optimization realizable:
  - PWR:
    - 10,000s of 3-D cycle depletions overnight
    - Stochastic algorithms have been very successful
  - BWR
    - 1000s of 3-D cycle depletions overnight
  - Needs:
    - BWR: simultaneous control rod pattern/fuel loading
    - Simultaneous optimization of bundle design and core loading
    - Multi-cycle optimization methods
    - Better understanding of "objective functions"

Current 3-D transient methods

- Needs for nodal method improvement:
  - Overcome same accuracy limitations as steady-state models
  - Improve cross sections modeling over the cold-to-hot range
  - Improve thermal-hydraulic models
- Needs for coupled nodal and systems-hydraulics codes:
  - More efficient numerics for massive numbers of t-h nodes
  - More accurate information on local thermal-hydraulic conditions
  - Improved mechanistic models for spacers, dryout, DNBR, etc.
  - Improved 3-D vessel components modeling: vessel mixing, cross flow, bypass flow channels, etc.
- Needs for 3-D fine-mesh transient methods:
  - Same thermal hydraulic limitations as nodal methods

Needs for better plant monitoring

- Much LWR analysis is necessitated by lack of detailed knowledge of in-core power distributions
(e.g. PWR "flyspeck analysis")

- What about licensing new methods for monitoring plant operations?
  - Need reliable fixed in-core detection system
  - Need real-time detailed modeling of core power distributions, DNBR margins
  - Better tools for operator support

Is the grass greener on the other side?

- Much of the need for complex methods for LWRs is driven by the difficulties caused by high pressure water coolant
- Can new reactor concepts (NGNP, GEN IV) <u>avoid</u>:
  - The licensing requirements for accurate/complex computations?
  - The need for plant and cycle-specific analysis?
  - Introduction of new materials and chemistry problems?
  - Economic pressure to operate closer to physical limits?

Summary

- All reactor physics problems have not been solved!
- Advances in computational hardware will not eliminate the need for new deterministic reactor physics tools.
- New reactor types may well stress different areas of reactor physics than do LWRs.
- New reactor physics projects are needed to fully educate the coming generation of reactor physicists.
- <u>Completion</u> of new reactor projects is required to keep reactor physics a relevant and vibrant discipline.